



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>5</sup> :

G01N 23/083

A1

(11) International Publication Number:

WO 92/02808

(43) International Publication Date:

20 February 1992 (20.02.92)

(21) International Application Number: PCT/US91/05620

(22) International Filing Date: 7 August 1991 (07.08.91)

(30) Priority data:

564,156

7 August 1990 (07.08.90)

US

(60) Parent Application or Grant

(63) Related by Continuation

US

Filed on

564,156 (CON)

7 August 1990 (07.08.90)

(71) Applicant (for all designated States except US): HOLOGIC, INC. [US/US]; 200 Prospect Street, Waltham, MA 02154 (US).

(71)(72) Applicant and Inventor: STEIN, Jay, A. [US/US]; 15 Carter Drive, Framingham, MA 01701 (US).

(74) Agent: WILLIAMS, John, N.; Fish &amp; Richardson, 225 Franklin Street, Boston, MA 02110 (US).

(81) Designated States: AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH (European patent), CI (OAPI patent), CM (OAPI patent), CS, DE (European patent), DK (European patent), ES (European patent), FI, FR (European patent), GA (OAPI patent), GB (European patent), GN (OAPI patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU (European patent), MC, MG, ML (OAPI patent), MN, MR (OAPI patent), MW, NL (European patent), NO, PL, RO, SD, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

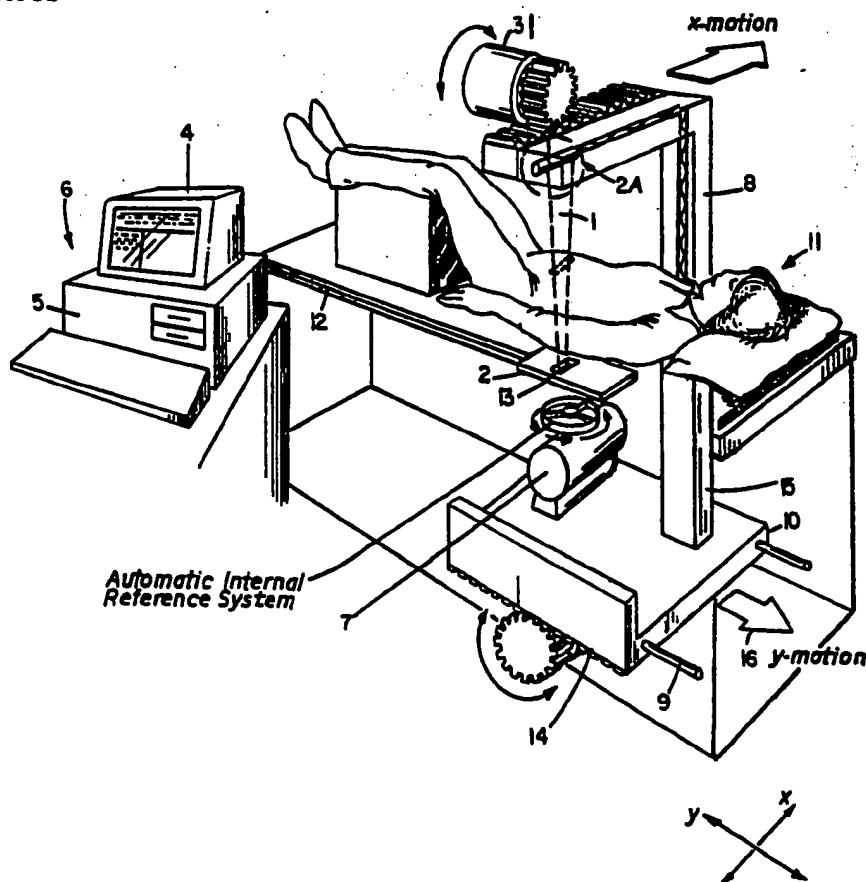
Published

With international search report.

(54) Title: X-RAY ANALYSIS APPARATUS

## (57) Abstract

X-ray analysis apparatus and related method including a bone densitometer apparatus, in which detectors (3) are translatable in the plane of the beam (1) for each scan line to provide enhanced resolution and detector-to-detector normalization. In this motion the x-ray source (7) is stationary. Indexing or moving from one scan line to the next involves relative movement between the object or patient (11) and the x-ray means (7) and detector array (3) which are fixed in relationship to each other.



# + DESIGNATIONS OF "SU"

It is not yet known for which States of the former Soviet Union any designation of the Soviet Union has effect.

## *FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MG	Madagascar
AU	Australia	FI	Finland	ML	Mali
BB	Barbados	FR	France	MN	Mongolia
BE	Belgium	GA	Gabon	MR	Mauritania
BF	Burkina Faso	GB	United Kingdom	MW	Malawi
BG	Bulgaria	GN	Guinea	NL	Netherlands
BJ	Benin	GR	Greece	NO	Norway
BR	Brazil	HU	Hungary	PL	Poland
CA	Canada	IT	Italy	RO	Romania
CF	Central African Republic	JP	Japan	SD	Sudan
CG	Congo	KP	Democratic People's Republic of Korea	SE	Sweden
CH	Switzerland	KR	Republic of Korea	SN	Senegal
CI	Côte d'Ivoire	LI	Liechtenstein	SU <sup>+</sup>	Soviet Union
CM	Cameroon	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
DE	Germany	MC	Monaco	US	United States of America
DK	Denmark				

## X-RAY ANALYSIS APPARATUS

Background of the Invention

This invention relates to x-ray analysis apparatus.

In one important type of x-ray analysis apparatus,  
5 radiation is used to measure the density and distribution of  
bone in the human body. This procedure is helpful in  
diagnosing bone disease such as osteoporosis. Since this  
diagnostic technique uses potentially harmful ionizing  
radiation, bone densitometers are typically constructed to  
10 minimize the radiation exposure by minimizing the duration  
of radiation exposure while at the same time using the  
lowest intensity of the radiation possible.

In general, in a bone densitometer, a patient is  
placed on a table while a radiation source passes radiation  
15 through the patient. A detector is positioned on the  
opposite side of the patient from the source to detect the  
unattenuated radiation. Both x-ray tubes and radioisotopes  
have been used as a source of x-ray radiation. In each case,  
the radiation from the source is collimated to a specific  
20 beam shape prior to reaching the patient. This collimation  
reduces the exposure of the patient to the predetermined  
region of the patient opposite which are located the  
detectors. Various x-ray beam shapes have been used in  
practice and include fan beam, pencil beam, and cone beam  
25 shapes.

The shape of the beam and the shape of the detector  
system correspond. The detector in a fan beam system is a  
linear array of detectors. The actual detectors which make  
up the array range from low cost silicon photodiodes coupled  
30 with a scintillation material for use with higher intensity

- 2 -

radiation to higher cost photomultiplier tubes coupled with scintillation material for use with low intensity radiation.

Since in bone densitometry the intent is to reduce the radiation exposure to the patient and since only a small percentage of x-rays penetrate the patient, highly sensitiv  
5 photomultiplier tubes with scintillation crystals are useful. Such photomultiplier detectors are expensive, thos of lowest cost being relatively large and therefore of relatively low inherent resolution.

#### 10 Summary of the Invention

According to an important aspect of the invention, an x-ray analysis apparatus comprises an x-ray means which generates and projects at least one x-ray beam in a plane transverse to an object, and detector array means arranged  
15 on the opposite side of the object to detect x-rays to produce signals corresponding to the amount of x-rays transmitted through the object. The detector array means together with and in fixed relation to the x-ray means is movable relative to the object in a scanning direction  
20 normal to the beam through a multiplicity of scan line positions. Furthermore, the detector array means at each scan position of the x-ray means is movably driven relative to the x-ray means and the patient or other object in a second direction in the plane of the beam and transverse to  
25 the object, means being provided to produce multiple samples of the signal of the detector array means at each scan position of the x-ray means during the movement of the detector array means in the second direction. Signal processing means responsive to signals thus produced from  
30 the detector array means produces an indication of the nature of th object.

- 3 -

Preferred embodiments of this aspect of the invention include one or more of the following features.

The x-ray means comprises an x-ray source and a slit columnator that produces a fan beam.

5 The detector array means include a linear array of evenly spaced discrete detectors, the array being driven in translation relative to the x-ray means and object through at least two and preferably four sample positions for a distance of travel corresponding to the center-to-center  
10 distance between adjacent detectors whereby resolution is enhanced by the multiple nature of the samples taken by each detector in each given scan line.

The detector array means in each scan position of the x-ray means moves a distance corresponding to at least  
15 twice the center-to-center spacing of the detectors, and normalizing means are provided, responsive to detection of the same pixel by at least two detectors, over the set of detectors, for normalizing the response for the detectors in the array.

20 The x-ray source and detector array means are translatable in a direction orthogonal to the second direction to produce the movement in the scanning direction.

Alternatively, the x-ray source and detector means are rotatable to produce the movement in the scanning  
25 direction, for instance rotation relative to the object in a CT scanner implementation or rotation relative to the source to produce, in a somewhat simplified manner, a scan similar in effect to a linear scan, albeit with some distortion.

In the cases described, when employing this  
30 invention with a fan beam, when the detectors move in the plane of the beam, the source, columnator slit and patient or other object are stationary but when the detectors are moved normal to the beam the detectors are moved with and in

- 4 -

fixed relation to the source, and columnator slit, relative to the patient or object.

The detector means includes a linear array of detectors, wherein each detector includes a detector aperture through which detection takes place. This aperture can be a fixed dimension or a variable dimension controlled by a movable mask. The movable mask includes a radiation shield that can be moved in and out of the field of the detectors by a motor or solenoid. The detector array is provided with means to move in the direction of the fan at least equal to the center-to-center spacing of detectors in the array. The output of the detectors is typically sampled two to four times during its travel of one center-to-center distance. The translation in the direction in the plane of the beam can be either incremental or continuous, and is accomplished by a stepping motor in cooperation with a toothed belt, a stepping motor in cooperation with a lead screw, or a dc motor used with a position encoder and a toothed belt or lead screw.

Additional features of the preferred embodiments include a linear array of detectors with measurements in each detector used to normalize a neighboring detector in manner that all detectors can be normalized to each other. To achieve this result the linear array of detectors is adapted to translate a distance equal to more than one and preferably two center-to-center detector spacings in the direction perpendicular to the longitudinal scan direction and transverse to the object for every scan line, i.e., every increment of translation in the direction normal to the plane of the beam. Each detector in the array is adapted to produce detected signals which are compared for x-ray absorption value, which is dependant on the gain of the detectors. The x-ray absorption value is normalized for

- 5 -

the detectors, using a multiplying factor which is defined as the ratio of the gain of one detector as compared to the gain of a reference detector. The signals produced by the detectors need to be corrected for gain and offset as well.

5 To correct for the offset in each channel, the signals measured when no x-rays are on is recorded and subtracted from signals when x-rays are on. The gain correction is implemented in a more complicated fashion. By causing each pair of adjacent detectors to travel sufficiently to record  
10 identical rays through the patient at some stage during the motion of the detectors in the plane of the fan, the measurements of identical rays by the two detectors can be used to normalize the gain between the two detectors. In this manner, detector two is normalized to detector one,  
15 detector three to detector two, detector four to detector three, etc. In order to obtain identical rays measured by two adjacent detectors, as maintained above, the distance of travel of the array along the fan must be more than one center-to-center spacing and preferably two full center-to-  
20 center spacings. The gains measured can include an average of the detector gains over a longitudinal scan, an average of the gains over a single scan line, to the object, or determining the gain from a slope-intercept graphing method.

Preferred embodiments also include a power supply  
25 which generates a low energy x-ray pulse and a high energy pulse and the calibrating means described in the above referred to applications which are hereby incorporated by reference. The power supply includes a stationary anode adapted to use 1 to 3 milliamps of current. The x-ray means  
30 includes fan-producing columnator slits, large and small, with one embodiment being 1 mm in width. The detectors are large, high sensitivity detectors including scintillation

- 6 -

detectors in cooperation with photomultiplier tubes. There are approximately 30 rectangular detectors in the array.

According to another aspect of the invention, a bone densitometer apparatus for measuring the bone density of a patient having a length and a thickness includes an x-ray tube means and associated power supply which generates and projects at least one x-ray beam in a plane of the patient. Detector means are arranged on the opposite side of the patient to detect x-rays and produce signals corresponding to the amount of x-rays transmitted through the patient. These detector means are translatable in a direction normal to the plane of the beam and in a direction in the plane of the beam and transverse to the patient. Signal processing means are also included which are responsive to signals from the detector means to produce data on the nature of the bone density of the patient.

Preferred embodiments of this aspect include x-ray exposure along the length of the patient, x-ray exposure laterally along the thickness of the patient, and means used to orient the detection means so that they are adapted to expose the x-ray laterally along the thickness of the patient.

According to another aspect of the invention, a method of performing x-ray analysis on an object includes generating at least one x-ray beam in a plane, exposing the object by passing the x-ray beam through it, detecting the x-rays attenuated by the object using detectors, translating the detectors and the beam in unison in a direction normal to the plane of the x-ray beam to perform a scan on the object, translating the detectors in a direction perpendicular to the plane of the beam and transverse to the object, and processing signals from detected x-rays.



- 7 -

According to another aspect of the invention, a method of increasing resolution in x-ray analysis includes scanning an object longitudinally using an x-ray beam in the plane of the object, detecting through x-ray radiation with a linear array of detectors, each detector in the linear array includes a detector dimension over which the detector can determine x-ray absorption value, and translating each detector in increments perpendicular to the scanning direction and transverse to the object, these increments being smaller than the detector dimension.

According to another aspect of the invention, a method of performing normalization in x-ray analysis includes scanning an object longitudinally to the object using an x-ray beam in the plane of the object, detecting through x-ray radiation with a linear array of detectors wherein each detector has a gain and a detector dimension over which the detector can determine x-ray absorption value (dependant on the gain), translating the linear array of detectors in a direction perpendicular to the scanning direction and transverse to the object so that each detector moves a distance of at least two detector dimensions, comparing the gain of each detector with a gain of at least one other detector for x-ray absorption value, and adjusting the gain of each detector by a correction factor.

This invention has the advantage of performing a high resolution scan using a small percentage of high sensitivity detectors, thereby reducing cost. It also has the capability to perform lateral scans across the thickness of the body which is essential to gather necessary information about the curvature of the spine. Additionally, it provides for a normalized result which guarantees higher accuracy.

- 8 -

Other advantages and features will become apparent from the following description of the preferred embodiment and from the claims.

### Brief Description of the Drawings

5           A more complete understanding of the invention may be obtained from the following detailed description when taken in conjunction with the drawings, in which:

Fig. 1 is a diagrammatic representation of an embodiment of the invention.

10           Fig. 1a is a diagrammatic sideview, Fig. 1b an endview and Fig. 1c a topview of an apparatus for performing a lateral scan;

Fig. 2 is a diagrammatic illustration of an x-ray detector of the preferred embodiment. Fig. 2A is a  
15 diagrammatic illustration of an x-ray detector array comprising the detectors of Fig. 2.

Fig. 3, positions (1) to (3), together with Fig. 1a is a schematic representation of sampling in a single scan pattern as performed in accordance with the invention.

20           Fig. 4 is a schematic representation of multiple scans as performed in accordance with the invention.

Fig. 5A is a diagrammatic illustration of another embodiment of a detector array. Fig. 5B is a diagrammatic illustration of the detector array of Fig. 5A with a mask.

25           Fig. 6 positions (5) to (8) together with Fig. 3 is a schematic representation of sampling in a single scan line during normalization.

### Description of the Preferred Embodiment

30           An embodiment of a fan beam bone densitometer is depicted in Fig. 1. A patient 11 lies horizontally during scanning on a table 12. X-ray radiation produced by source

- 9 -

7 located beneath the table 12 is transmitted through the patient 11 to an array of detectors, see Fig. 2A, located above the patient.

In more detail, the x-ray source 7 in this embodiment has a stationary anode. Adjacent the source 7 is a slit collimator 13 made of an x-ray opaque material such as lead or tungsten in which one or more selectable slits has been machined. The preferred embodiment includes a 1mm collimation slit. The x-ray radiation from the source 7 passes through the slit in the collimator 13 and forms a fan shape in space. The width of the beam at the plane of the patient may be such that the width of the patient is completely covered during the scan so that complete skeletal information can be determined, or as often preferred in bone densitometry, the width of the fan may be narrowed depending upon the application, for example to scan a spine only. The x-ray beam not only has width, but also thickness, defined by the width of the slit in the collimator. A scan line is defined by the area of the patient irradiated, i.e. the width and thickness of the x-ray beam over which density data is collected at one point in time. A complete bone densitometry scan measurement therefore consists of a series of adjacent scan lines such that the entire region of interest has been measured.

Opposite the x-ray source 7, approximately thirty detectors 50 are arranged in a linear configuration which spans a part of the width of the patient. The detector array 3 is located on a movable gantry structure 8, and has the capability of moving in two orthogonal directions. In one direction, the detectors move with the gantry 8 and base 10 in fixed relation to the source 7 and collimator slit 13, in a direction perpendicular to the plane of the fan beam which we will refer to as the Y direction, which extends

- 10 -

longitudinally along the patient. The detectors also move in the direction along the upper arm of the gantry in the plane of the fan beam, which we will refer to as the X direction, lying transversely across the patient.

5 To perform a scan, as stated previously, a series of transverse scan lines of data must be acquired. To do this, the x-ray source and the detectors are moved in fixed relation to one another in the Y direction along the patient by moving the gantry 8 and base 10. This motion in the Y  
10 direction is responsible for moving the array 3 and source 7 to the next successive scan line during the performance of a complete scan.

This motion can constitute incremental steps or continuous motion. A drive mechanism 14 accomplishes this.  
15 For relatively large systems, a toothed belt in cooperation with a stepping motor is utilized to move the gantry 7 and base 10, whereas for relatively small systems, a lead screw is used in cooperation with a stepping motor or position encoder. If continuous motion is utilized, the position of  
20 the detector array at any time can be determined by counting the steps in a stepping motor.

As depicted in Figure 1, the patient is scanned such that x-ray radiation impinges on the back of the patient and exits through the front of the patient (i.e. the chest).  
25 With this system, it is also possible to scan the patient such that x-ray radiation impinges on one side of the patient (i.e. the shoulder) and exits from the other side. For this type of scan, a mechanism is provided (but not shown) which shifts the position of the gantry structure 8  
30 including the detector array 3 and the x-ray source 7 ninety degrees about the longitudinal axis of the patient. This type of lateral scanning is beneficial because it allows the physician to gather additional information relating to the

- 11 -

spinal cord, such as analysis of the isolated vertebral body. In this example, the radiation travels through a thicker section of the object and less radiation is available to strike the detectors. Therefore, it is even  
5 more important to utilize highly sensitive detectors such as those described above.

The lateral scan approach is illustrated in diagrammatic Figs. 1a, 1b and 1c.

10 Additionally, the detector array 3 is moved in the X direction relative to the x-ray source and slit collimator by a stepping motor 15. This motion is shown diagrammatically for the lateral scan case during a single scan line by the series of positions of Figs. 3 and 6, subfigures (1) through (8), for the case where the detector  
15 array moves over the range of two center-to-center spacings. The important purpose of this x-motion will be described in detail shortly.

In another embodiment of the invention, for achieving the necessary motion, table 11 is moved in the Y  
20 direction rather than moving the base, gantry, x-ray source and detector array. The movement of the table passes the patient through the stationary fan beam to perform the scanning. The table can also be translated in this motion by a stepping motor.

25 The signals produced by the detectors at successive scan lines are digitized by an analog to digital (A/D) converter in computer 6 and stored on disk. The computer 6 processes the signals from the A/D into density representations and images. To form the images from the  
30 density data, the computer 6 transforms the digitized density information to a plurality of areas of varying light intensity, displaying this data as picture elements or pixels of a visual image on a video display 4. The video

- 12 -

display is capable of displaying both density data and images for viewing by the physician or medical technician.

In more detail, Fig. 2 illustrates an embodiment of a type of detector which can be utilized in this system.

5 The detector 50 includes a scintillation crystal 52 which produces light when struck by the x-ray radiation emitted by the x-ray source 7. The light produced by the crystal 52 is related to the intensity of the x-ray radiation striking it. Adjacent to the scintillation crystal 52 is a  
10 photomultiplier tube 54 which amplifies the light produced by the scintillation crystal 52, and generates an electrical signal related to the amount of light produced by the crystal 52. The combination scintillation crystal 52 and photomultiplier tube 54 acts as a highly sensitive x-ray  
15 detection device, desirable because of the low level of radiation to which the patient is exposed, especially during a lateral scan. Other detectors such as photodiodes generally are more difficult to use to detect these low levels of radiation. In one embodiment of a bone  
20 densitometer, x-ray photons enter the scintillation crystal 52 through an aperture mask 58 which concentrates the photons on one spot on the crystal 52.

Referring to Fig. 2A, a series of detectors 50 are arranged in the linear array 3 of approximately twenty to  
25 thirty detectors. Each detector 50 generates a signal which provides an indication of the density of bone at the location of the detector within one scan line. As described above, the detectors utilized are highly sensitive. However, these highly sensitive detectors may be too big to  
30 supply the resolution sometimes required for certain applications. The invention solves this problem.

In one embodiment, adjacent and relatively small photomultiplier detectors, or, large detectors having masks

- 13 -

that make their effective sensitive area small, are positioned such there is a 0.5" distance from the center of one detector to the center of another detector, i.e. center-to-center spacing. The relatively large spacing reduces the number of detectors required to cover the desired width of the patient scanned and thereby reduces the cost of the detector array. Each detector 50 generates a signal which provides an indication of the density of bone at the location of the detector within one scan line.

10 To achieve desired resolution without increasing the number of detectors, the entire detector array is moved along the direction of the scan a distance equal to at least one center-to-center spacing and preferably two. Fig. 3 is a schematic representation of how the detector array 3 is  
15 incrementally moved across the patient to increase resolution (only a few detectors are denoted, and each detector is provided with a number of marks by which the successive sampling positions can be understood). An integral number of samples is taken as the array moves for  
20 instance one center-to-center spacing. In this embodiment each detector d is sampled at four evenly spaced increments of approximately 0.125" each for each center-to-center distance of travel. This generates signals which are somewhat comparable to a system with four times the number  
25 of detectors, thereby increasing the resolution of the system significantly.

In more detail, the motion of the detectors is as follows, referring also to the schematic of Fig. 3. There are (n) detectors 50 denoted (d) in the array utilized to  
30 detect the level of x-ray radiation which passes through the body and thereby, to determine the bone density of the patient. Each detector,  $d_n$ , begins in a home position at

- 14 -

time  $t_0$  such that the detector aperture is position  $d$  at  $d_n^{t_0}$ , see also Fig. 1a.

In the embodiment, the detectors are spaced such that the effective detector aperture is one-fourth of the center-to-center spacing between detectors. By moving the detector array in the X direction and taking multiple samples per center-to-center detector spacing, measurements then cover all of the space across the patient's scan field. This x-ray image comprises various pixels derived from information taken from every detector in the array at increments small compared to the detector spacing.

To illustrate this, the detector array and source are positioned in the first scan location, see Fig. 1a, and a sample is taken. Each detector is moved in the X direction (as depicted by arrow 60) and at the next position  $d_n^{t_1}$  at time  $t_1$ , a sample is taken. Following that, the detector array is moved to position  $d_n^{t_2}$ , a sample is taken, and similarly to  $d_n^{t_3}$  to complete four incremental samples of the detector signals in one scan line. This creates an output equivalent to that of a detector array having four times the number of detectors (i.e. an array including 30 detectors will have the resolution of an array having 120 detectors) and therefore, increases the resolution of the system by a factor of four. Following this motion in the X direction, the detector array, source and slit can be translated in fixed relationship to one another, one increment in the Y direction to prepare for another scan line. (In fact, in the embodiment of Figs. 1a-1c, for purposes elsewhere explained, before advancing to another scan line five more incremental samplings are taken). The detectors are again translated and are sampled at four points in the plane of the fan beam. This motion is in th



- 15 -

negatively X direction, thus restoring the detectors to their original position. These steps move the detectors from  $d_n^{t4}$  to  $d_n^{t5}$  and  $d_n^{t6}$  and finally to  $d_n^{t7}$ . Fig. 4 illustrates the proper scanning motion of the detectors in the X direction (as depicted by arrow 65) and the Y direction (as depicted by arrow 70) in such an embodiment. The scanning continues in this back and forth X motion and forward Y motion until a complete scan has been performed. Of course, an alternate embodiment can include scanning in the plane of the fan beam in only one direction, instead of back and forth.

An alternate embodiment of the system described above includes utilizing detectors that are larger than the increment of advance between sampling. Larger detectors are typically easier to mount in array form. Referring now to Figs. 5A and 5B, a method of varying the effective detector size is disclosed. A detector array including larger detectors will result in a scan having a better signal to noise ratio, whereas a detector array having smaller effective detectors with spacings between adjacent detectors will result in improved resolution using the X-motion scanning described above, at the expense of signal to noise ratio.

Fig. 5A illustrates a linear detector array 90 including relatively large detectors 92, i.e. each detector is approximately 0.5" on a side, which are arranged such that adjacent detectors abut one another. This detector array is sampled four times during the time the array moves one center-to-center distance. There is overlap between detectors during these samples which reduces the resolution, however even with the overlap the resolution is improved over a system where no X direction movement of the detection is employed, while the larger detector area greatly

- 16 -

increases the signal to noise ratio. This feature is very helpful during the side-to-side or lateral scans described earlier because the signal is reduced a significant amount as the x-ray travels through the thickness of the body.

5           Fig. 5B illustrates the same detector array 90 as shown in Fig. 5A with a lead shield or mask 94 placed over the detector array. This mask blocks out the radiation from the portions of the array that it covers and therefore effectively creates a detector array having detectors with  
10 relatively smaller dimensions than those of Fig. 5A. The mask 94 is moved into and out of position on the detector array through the use of a solenoid. The mask when moved into position is effectively attached to and moves with the detector array during both the X and Y scan direction. This  
15 array reacts similarly to the detector array described with reference to Fig. 2A. Again, the detector array is sampled in the X-direction in smaller increments than the effective detector dimension to increase resolution. This arrangement has a poorer signal-to-noise ratio than the unmasked  
20 arrangement of Fig. 5A, but has improved resolution over that of Fig. 5B arrangement. The arrangement is useful for tasks requiring high resolution, such as obtaining high quality images of the bones.

          In many instances, the detectors vary in their gain  
25 and therefore will not produce the same signals when exposed to the same x-ray radiation intensity. Therefore, one detector may create an output signal which is higher or lower than the output of another detector. The technique of the invention can be used for normalizing the detectors to  
30 produce consistent results.

          The complete set of positions of Figs. 1a; 3 and 6 illustrate such a normalization process. As the detector system scans the patient (as represented by arrow 80) th

- 17 -

radiation in the area corresponding to each pixel is detected by two distinct, adjacent detectors. These two separate signals are "normalized" to a single standard value, which means that the gain of each detector is adjusted to equal the gain of a given detector. Additionally, an offset value is determined for each detector and must be adjusted accordingly. The offset is defined as a residual or dark current in the detector that exists when the detector is not being exposed to x-rays. The offset value is determined for each detector before the x-ray source is powered (i.e., before the scan is taken), and the offset value is subtracted from each measurement taken before the normalization.

Each detector is normalized by comparing the output signal of that detector with an output signal of another detector utilized to measure the identical location on the patient's body. Effectively the gain of detector number one  $d_1$ , is fixed as a reference. By comparing the measurements in detector  $d_2$  that correspond to the same pixels as detected by  $d_1$ , the gain of detector  $d_2$  is normalized to detector  $d_1$ ; then by comparing the measurements in detector  $d_3$  that correspond to the same pixels as detected by  $d_2$ , the gain of detector  $d_3$  is normalized to the gain of detector  $d_2$  and so on, so that all detectors are in effect normalized to detector  $d_1$ .

For example, pixel  $P_c$ , a representative point of the body being scanned, in Figs. 1a, 3 and 6 can be measured during the scan by three detectors  $d_1$ ,  $d_2$ , and  $d_3$  during the course of the detector array translation at corresponding times  $t_0$ ,  $t_4$ , and  $t_8$ , respectively. As an example, let detector  $d_1$  be used as the reference and the measured value

- 18 -

for detect  $r d_2$  is then scaled by a multiplication factor so that the result equals the measured result at detector  $d_1$ .

In an actual system, rather than use a single pixel for comparison of two detectors, all pixels scanned by the same set of detectors in a single scan line or over the entire X, Y scan can be used to calculate an average correction factor which is then used for the respective detector for all measurements made in the scan. The average gain measured over the entire scan for detector  $d_2$  can thus be normalized to the average gain measured over the entire body scan for a chosen reference detector such as  $d_1$ , and likewise the average gain of detector  $d_3$  measured over the entire scan can be normalized to the average gain for detector  $d_2$  and so on. Such an average can be utilized in order to reduce the error in the correction factor. Another method of normalization would be to average the detector gains over each scan line in the X-direction and adjust the gains after each successive scan line is taken.

Normalization actually does not occur in real time, but occurs after all the scans have been completed and the data is input into the computer. A computer manipulation occurs which normalizes each detector over all of the pixels measured by that detector. For example, pixel  $P_c$  is detected by detectors  $d_1$  and  $d_2$ . Therefore, once detector  $d_2$  has been normalized to detector  $d_1$  for the entire scan, the gain of detector  $d_2$  will be adjusted to properly represent all pixels. Of course, the offset value has already been subtracted from the gain measurement.

A graphical normalization technique operative on the signals of neighboring detectors can be implemented by computer in an alternative embodiment. The intercept

- 19 -

represents the offset correction and the slope of the curve, the gain correction factor.

While the scanning motion of the x-ray source, slit columnator and detector array has been illustrated as translation in the y coordinate, other scanning motions are possible. For instance the assembly could be rotated about a line in the plane of the fan beam passing through the x-ray source as center, to approximate translation in the x direction, in a mechanical movement that is simpler to implement. In the case of a CT scanner embodiment, the assembly can be rotated about an axis perpendicular to the fan beam that passes through the center of the patient.

This disclosure has described a fan beam system for a bone densitometer, but this same system could be applied to other types of x-ray scanners such as CT scanners and baggage inspection systems as well.

Other embodiments of the invention are within the following claims.

What is claimed is:

## Claims:

- 20 -

1           1. An x-ray analysis apparatus comprising  
2           an x-ray means which generates and projects at least  
3 one x-ray beam in a plane transverse to an object,  
4           detector array means arranged on the opposite side  
5 of the object to detect x-rays to produce signals  
6 corresponding to the amount of x-rays transmitted through  
7 the object,  
8           said detector array means, together with and in  
9 fixed relation to said x-ray means, being movable relative  
10 to the object in a scanning direction normal to the beam  
11 through a multiplicity of scan line positions,  
12           and said detector array means at each scan line  
13 position of said x-ray means being movably driven relative  
14 to said x-ray means and said object in a second direction in  
15 the plane of the beam,  
16           means to produce multiple samples of the signals of  
17 the detector array means at each scan line position of said  
18 x-ray means during said movement of said detector array  
19 means in said second direction,  
20           and signal processing means responsive to signals  
21 from the detector array means to produce an indication of  
22 the nature of the object.

1           2. The apparatus of claim 1 wherein said x-ray  
2 means comprises an x-ray source and a slit columnator that  
3 produces a fan beam.

1           3. The apparatus of claim 1 wherein said detector  
2 array means include a linear array of evenly spaced discrete  
3 detectors, said array being driven in said second direction  
4 in translation relative to said x-ray means and object  
5 through at least two sample positions for travel  
6 corresponding to the center-to-center distance between

- 21 -

7 adjacent detectors to enhance resolution by the multiple  
8 samples.

1           4. The apparatus of claim 3 wherein said detector  
2 array means in each scan position of said x-ray means moves  
3 a distance corresponding to at least twice the center-to-  
4 center spacing of the detectors, and normalizing means for  
5 each detector over the set of detectors responsive to  
6 detection of the same pixel by said detector and at least  
7 one neighboring detector, constructed to normalize the  
8 response for said detectors in a serial-dependent fashion  
9 over said array.

10           5. The apparatus of claim 1, 2, 3 or 4 wherein said  
11 x-ray source and detector array means are translatable in a  
12 direction orthogonal to said second direction to produce  
13 said movement in said scanning direction.

14           6. The apparatus of claim 1, 2, 3 or 4 wherein said  
15 x-ray source and detector array means are rotatable together  
16 to produce said movement in said scanning direction.

17           7. The apparatus of claim 6 wherein the said  
18 rotation is about a line in the plane of the fan beam  
19 passing through the x-ray source as center.

20           8. The apparatus of claim 6 wherein said rotation  
21 is about an axis perpendicular to the fan beam that passes  
22 through said object.

23           9. The apparatus of claim 3 wherein each detector in  
24 said linear array of detectors comprises a photomultiplier  
25 tube associated with a scintillation detector.

- 22 -

1           10. The apparatus of claim 9 wherein said detector  
2 receives x-rays through a restricted aperture.

1           11. The apparatus of claim 10 wherein said aperture  
2 is defined by a mask selectively moveable into position.

3           12. The apparatus of claim 11 wherein said mask  
4 comprises a radiation shield translatable by a solenoid.

1           13. The apparatus of claim 1 wherein said linear  
2 array of detectors is sampled at equally spaced positions  
3 between the center-to-center spacing of said detectors.

1           14. The apparatus of claim 13 wherein said  
2 positions are spaced apart  $1/4$  the dimension of said center-  
3 to-center spacing.

1           15. The apparatus of claim 4 wherein normalization  
2 comprises adjusting the gain of a second detector in said  
3 linear array of detectors by a correction factor, said  
4 correction factor comprising the difference between the gain  
5 of said second detector and the gain of a first neighboring  
6 detector used as reference, said second detector being used  
7 to correct the third detector in the same manner with said  
8 second detector as reference, and so on throughout the  
9 array.

1           16. The apparatus of claim 15 wherein said gain of  
2 each of said detectors comprises an average of gains  
3 measured for the respective detector during said scan.



- 23 -

1           17. The apparatus of claim 15 wherein said gain of  
2 each of said detectors comprises an average of gains  
3 measured for the respective detector during a scan line.

1           18. The apparatus of claim 15 wherein said gains of  
2 said detectors are determined from a slope-intercept  
3 graphing method.

1           19. The apparatus of claim 2 wherein said x-ray  
2 source comprises an x-ray tube and a power supply.

3           20. The apparatus of claim 19 wherein said power  
4 supply generates a low energy and high energy x-ray pulse.

1           21. The apparatus of claim 20 wherein said x-ray  
2 means further comprises a calibration wheel carrying  
3 segments of bone like material and segments having no bone  
4 like material for sequent lly passing through the pulses of  
5 high energy and low energy x-rays for repeated calibration  
6 of the apparatus.

1           22. The apparatus of claim 1 wherein said x-ray  
2 means includes selectable columnator slits, said columnator  
3 slits comprising a large slit and a small slit.

1           23. A bone densitometer apparatus for measuring the  
2 bone density of a patient comprising  
3 x-ray means comprising x-ray tube means, associated  
4 power supply and columnator slit which generates and  
5 projects at least one x-ray beam in a fan beam shape,  
6 detector array means arranged on the opposite side  
7 f th patient to d t ct x-rays to produce signals

- 24 -

8 corresponding to the amount of x-rays transmitted through  
9 the patient,

10 said detector array means together with and in  
11 fixed relation to said x-ray means being translatable in a  
12 direction normal to the plane of the beam, through a  
13 multiplicity of scan line positions,

14 and said detector array means at each scan line  
15 position of said x-ray means being translatable in a second  
16 direction in the plane of the beam,

17 means to produce multiple samples of the signals of  
18 the detector array means at each scan line position of said  
19 x-ray means during said movement of said detector array  
20 means in said second direction,

21 and signal processing means responsive to signals  
22 from the detector means to produce data on the nature of the  
23 bone density of the patient.

1 24. The apparatus of claim 23 further comprising  
2 means orienting said x-ray means and detection means to  
3 expose said patient to x-ray laterally along the thickness  
4 of the patient.

1 25. A method of performing x-ray analysis on an  
2 object comprising:

3 generating at least one x-ray beam in a plane;  
4 exposing the object by passing said x-ray beam  
5 through it;

6 detecting x-rays attenuated by the object utilizing  
7 detectors;

8 translating said detectors and said beam together in  
9 fixed relation in a direction normal to said plane of said  
10 x-ray beam through a number of scan line positions to  
11 perform a scan on the object;

- 25 -

12 translating said detectors in a directi n  
13 perpendicular to said plane of said beam relative to the  
14 source of said x-rays and the object;  
15 and processing signals from detected x-rays.

1 26. A method of increasing resolution in x-ray  
2 analysis comprising  
3 scanning an object utilizing an x-ray beam in a  
4 plane,  
5 detecting through x-ray radiation with a linear  
6 array of detectors, and  
7 translating each detector in said linear array of  
8 detectors in the plane of said beam and sampling in  
9 increments of travel that are smaller than the center-to-  
10 center dimension between detectors.

1 27. The method of claim 26 further including  
2 detectors in the form of photo multiplier tubes and  
3 associated scintillation crystals and a mask over said  
4 detectors to restrict the detection aparture of said mask.

1 28. The method of claim 26 wherein each detector in  
2 said linear array of detectors is sampled in increments of  
3 travel less then the center-to-center spacing of the  
4 detectors.

1 29. The method of claim 27 wherein the distance  
2 between sampling is between  $1/2$  and  $1/4$  of the center-to-  
3 center spacing of the detectors in said array.

1 30. A method of performing normalization in x-ray  
2 analysis comprising

- 26 -

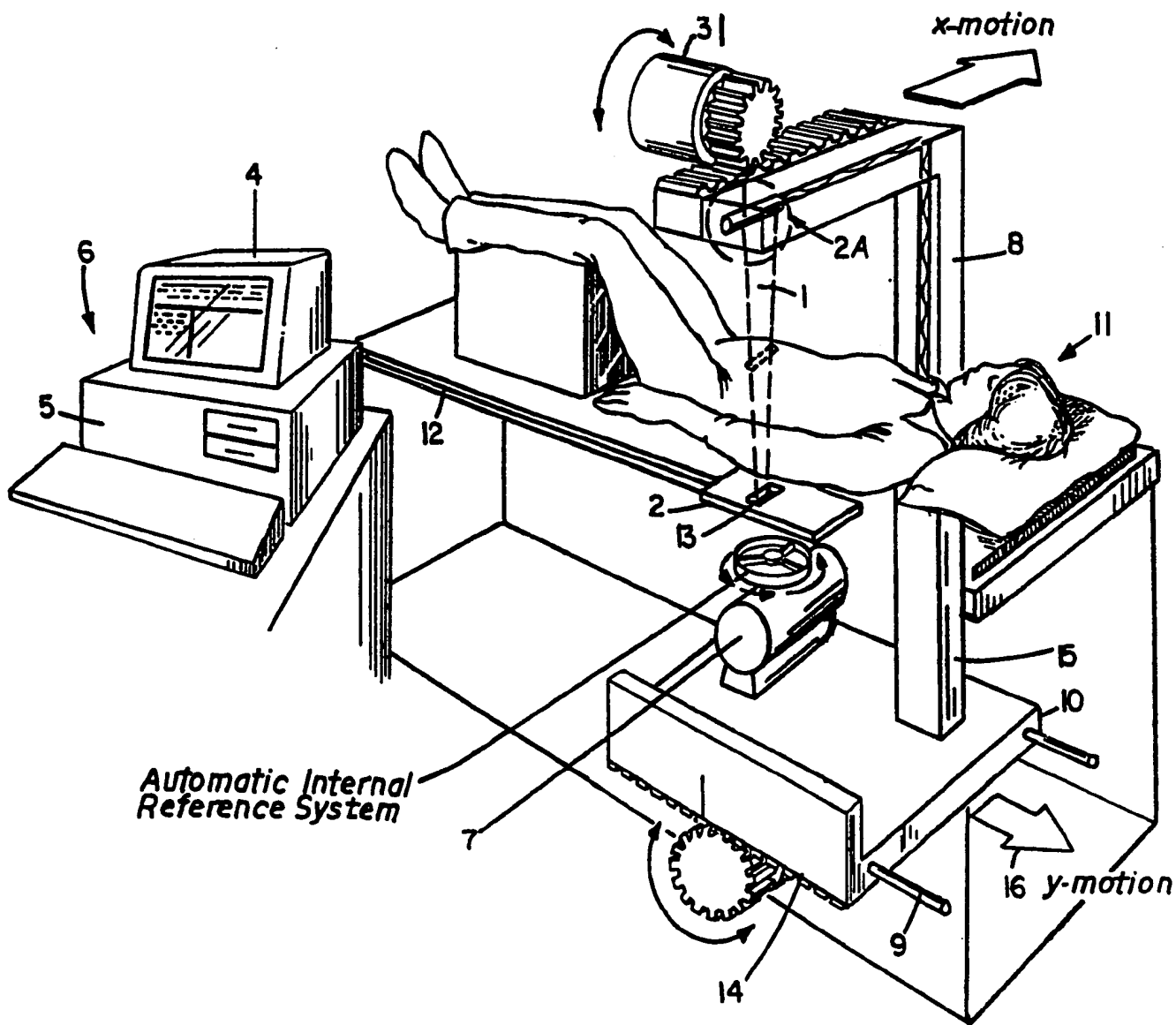
3 scanning an object utilizing an x-ray beam in a  
4 plane,  
5 detecting through x-ray radiation with a linear  
6 array of detectors,  
7 translating said linear array of detectors in the  
8 plane of the beam so that each detector in said linear array  
9 of detectors moves a distance of at least two detector  
10 dimensions, and sampling the signal of said detectors  
11 repeatedly in the manner that each detector detects x-rays  
12 at the same pixel as a neighboring detector,  
13 comparing said gain of each detector with a gain of  
14 said neighboring detector for said same pixel, and  
15 adjusting said gain of each detector by a correction  
16 factor dependent upon said comparison.

1 31. The method of claim 30 further comprising  
2 determining said correction factor as the difference between  
3 said gain of one detector and the gain of at least one other  
4 detector, said one detector being used as a standard.

1 32. The method of claim 31 further comprising  
2 averaging gains measured for said one detector during a  
3 scan, and comparing said average to an average of gains  
4 measured for at least one other detector during said scan.

1 33. The method of claim 30 further comprising  
2 averaging gains measured for said one detector during a scan  
3 line, and comparing said average to an average of gains  
4 measured for at least one other detector during a scan line.

1/5



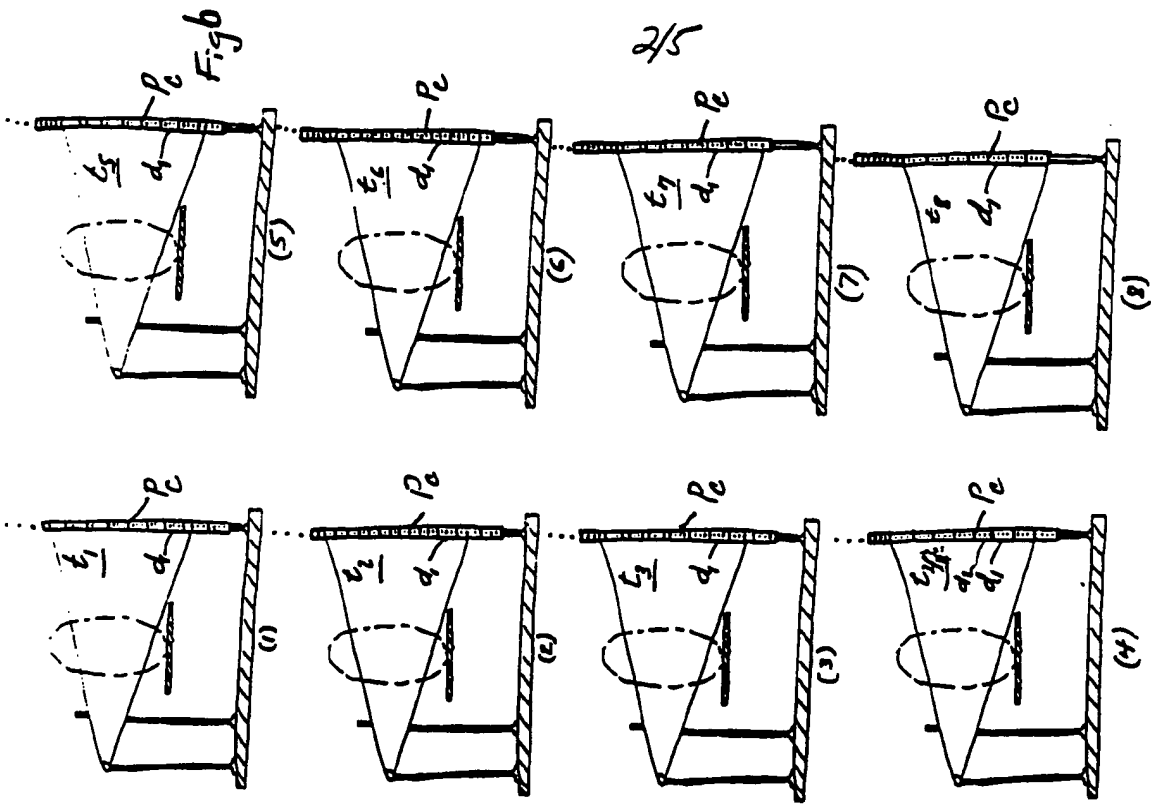


Fig. 3

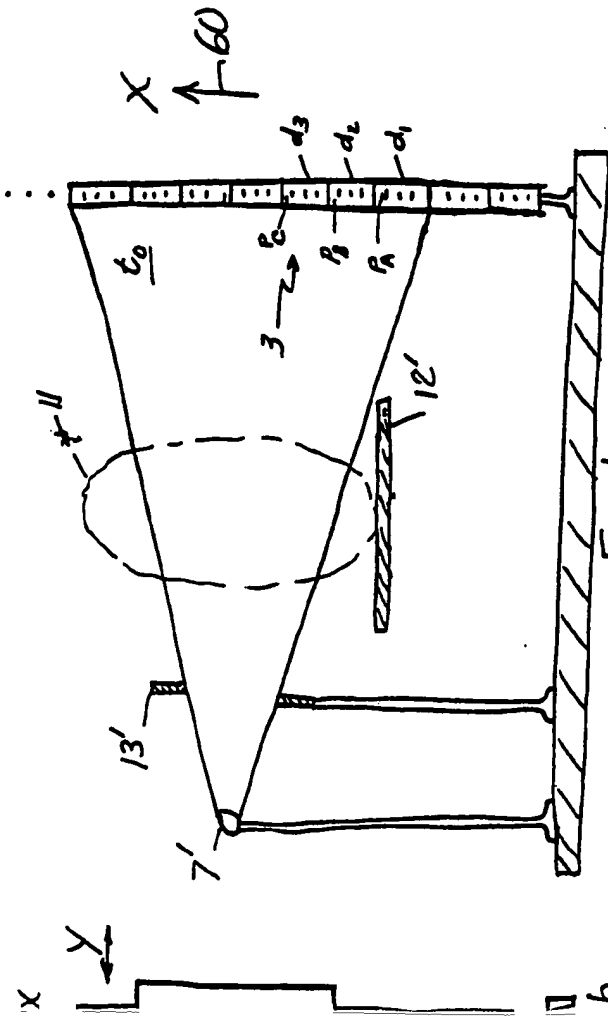


Fig. 1a

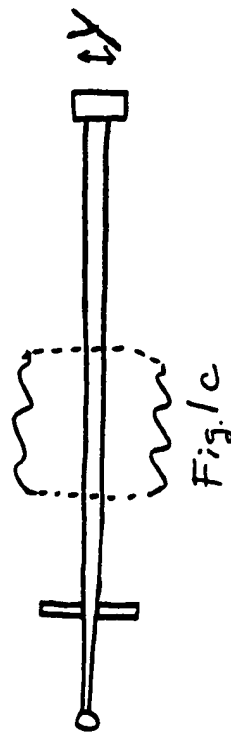
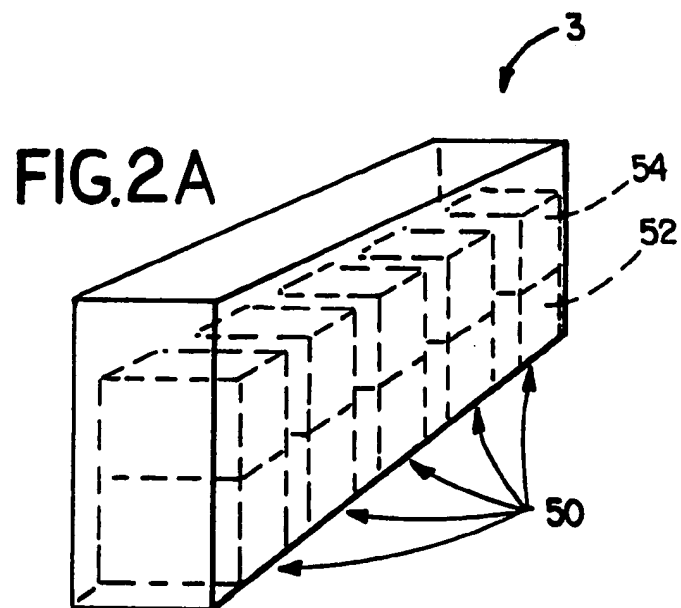
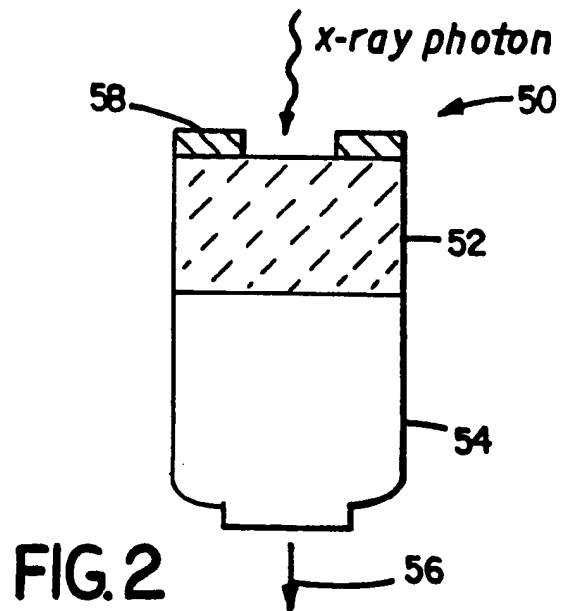


Fig. 1c

- 3 / 5 -



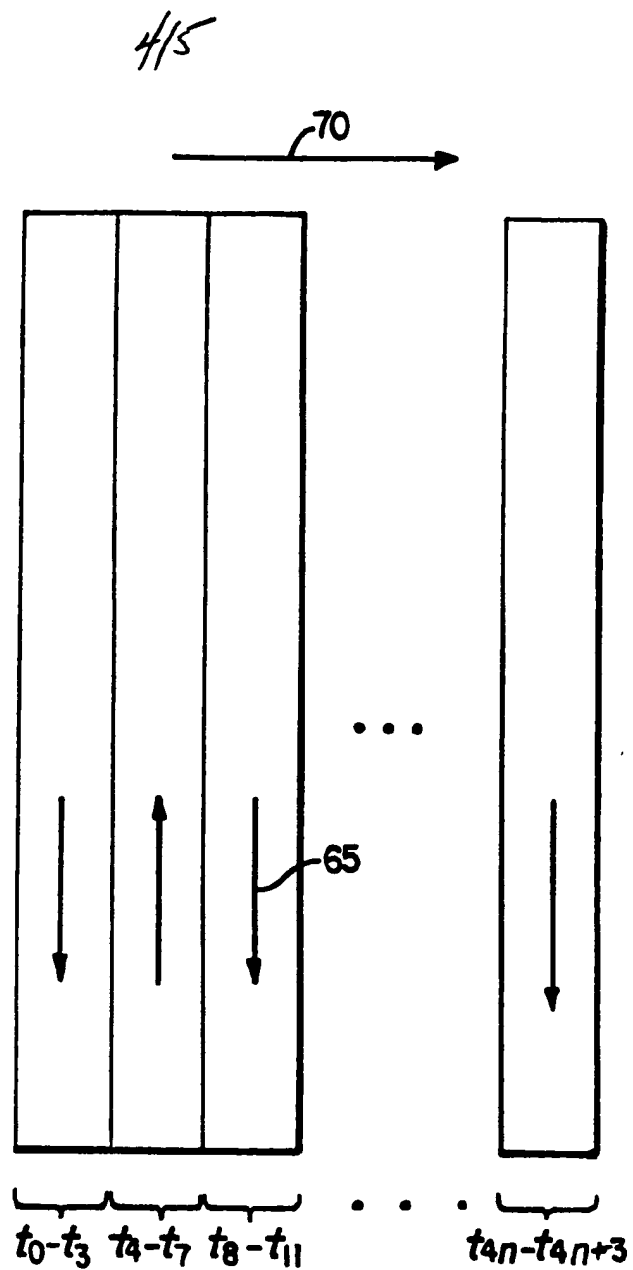


FIG.4



5/5

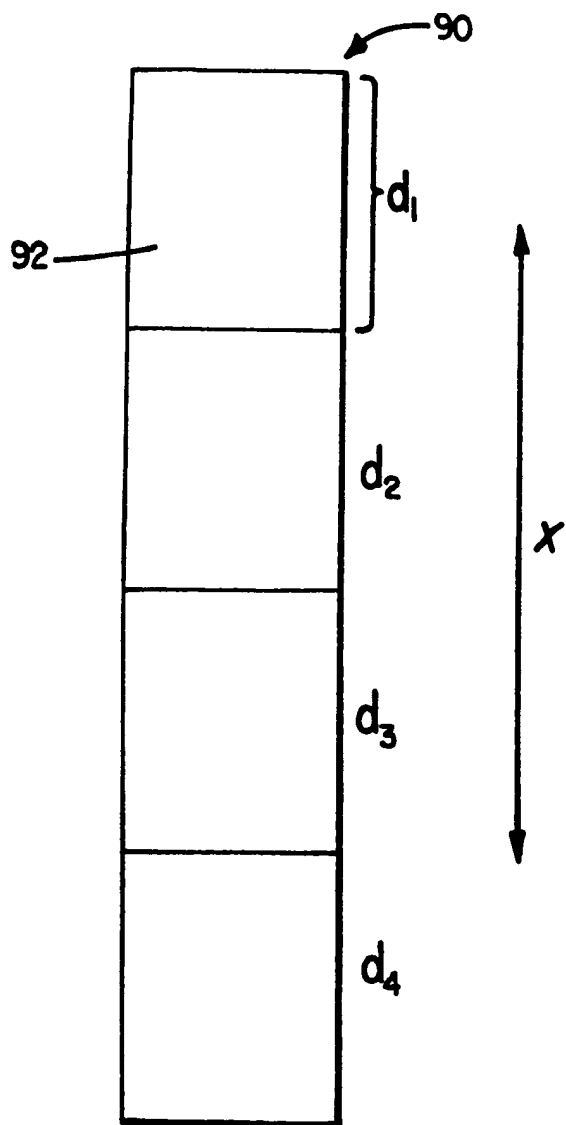


FIG. 5A

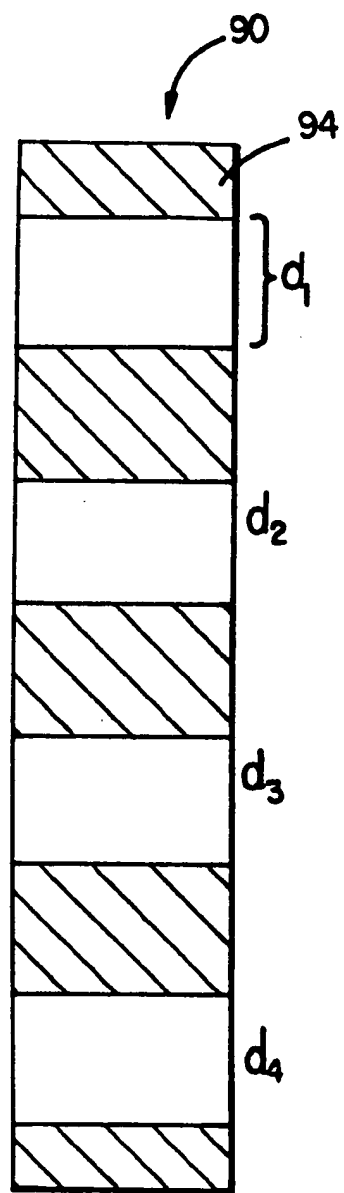


FIG. 5B

# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/05620

<b>I. CLASSIFICATION F SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup> According to International Patent Classification (IPC) or to both National Classification and IPC IPC(5): G01N 23/083 U.S. CL.: 378/55,56,62																	
<b>II. FIELDS SEARCHED</b> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Minimum Documentation Searched <sup>7</sup></div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; border-bottom: 1px solid black;">Classification System</td> <td style="border-bottom: 1px solid black;">Classification Symbols</td> </tr> <tr> <td style="height: 40px; vertical-align: bottom;">U.S.</td> <td style="vertical-align: bottom;">378/4,11,19,51-52,62,145-147,155,196</td> </tr> </table> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup></div>			Classification System	Classification Symbols	U.S.	378/4,11,19,51-52,62,145-147,155,196											
Classification System	Classification Symbols																
U.S.	378/4,11,19,51-52,62,145-147,155,196																
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT <sup>9</sup></b> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category <sup>9</sup></th> <th style="width: 70%;">Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup></th> <th style="width: 20%;">Relevant to Claim No. <sup>13</sup></th> </tr> </thead> <tbody> <tr> <td style="text-align: center; vertical-align: top;">X Y</td> <td style="vertical-align: top;">US,A, 4,644,578 (PAOLINI) 17 FEBRUARY 1987 see entire document</td> <td style="vertical-align: top;">1-3,5,13,14,19 23-26 9-14,20,27-29</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">X Y</td> <td style="vertical-align: top;">US,A, 4,639,941 (HOUNSFIELD) 27 JANUARY 1987 see entire document</td> <td style="vertical-align: top;">1-3,5,9-12,19, 22-28 4,5,13-18,20- 21,29-33</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">Y</td> <td style="vertical-align: top;">US,A, 4,029,963 (ALVEREZ et al.) 14 JUNE 1977 see entire document</td> <td style="vertical-align: top;">20</td> </tr> <tr> <td style="text-align: center; vertical-align: top;">Y</td> <td style="vertical-align: top;">US,A, 4,811,373 (STEIN) 07 MARCH 1989 see entire document</td> <td style="vertical-align: top;">20-21</td> </tr> </tbody> </table>			Category <sup>9</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>	X Y	US,A, 4,644,578 (PAOLINI) 17 FEBRUARY 1987 see entire document	1-3,5,13,14,19 23-26 9-14,20,27-29	X Y	US,A, 4,639,941 (HOUNSFIELD) 27 JANUARY 1987 see entire document	1-3,5,9-12,19, 22-28 4,5,13-18,20- 21,29-33	Y	US,A, 4,029,963 (ALVEREZ et al.) 14 JUNE 1977 see entire document	20	Y	US,A, 4,811,373 (STEIN) 07 MARCH 1989 see entire document	20-21
Category <sup>9</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>															
X Y	US,A, 4,644,578 (PAOLINI) 17 FEBRUARY 1987 see entire document	1-3,5,13,14,19 23-26 9-14,20,27-29															
X Y	US,A, 4,639,941 (HOUNSFIELD) 27 JANUARY 1987 see entire document	1-3,5,9-12,19, 22-28 4,5,13-18,20- 21,29-33															
Y	US,A, 4,029,963 (ALVEREZ et al.) 14 JUNE 1977 see entire document	20															
Y	US,A, 4,811,373 (STEIN) 07 MARCH 1989 see entire document	20-21															
<div style="display: flex; justify-content: space-between;"> <div style="width: 48%;"> <p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on prior art claim(s) or which is cited to establish the publication of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 48%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p> </div> </div>																	
<b>IV. CERTIFICATE</b> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; border-bottom: 1px solid black;">Date of the Actual Completion of the International Search</td> <td style="width: 50%; border-bottom: 1px solid black;">Date of Mailing of this International Search Report</td> </tr> <tr> <td style="border-bottom: 1px solid black;">25 SEPTEMBER 1991</td> <td style="border-bottom: 1px solid black; text-align: center;">22 OCT 1991</td> </tr> <tr> <td style="border-bottom: 1px solid black;">International Searching Authority</td> <td style="border-bottom: 1px solid black;">Signature of Authorized Officer</td> </tr> <tr> <td style="border-bottom: 1px solid black;">ISA/US</td> <td style="border-bottom: 1px solid black; text-align: center;">             DAVID P. PORTA         </td> </tr> </table>			Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	25 SEPTEMBER 1991	22 OCT 1991	International Searching Authority	Signature of Authorized Officer	ISA/US	 DAVID P. PORTA							
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report																
25 SEPTEMBER 1991	22 OCT 1991																
International Searching Authority	Signature of Authorized Officer																
ISA/US	 DAVID P. PORTA																

## FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☒ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE \*

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers \_\_\_\_\_, because they relate to subject matter <sup>12</sup> not required to be searched by this Authority, namely:

2. ☒ Claim numbers 6-8, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out <sup>13</sup>, specifically:

It is not clear from the specification how the assembly is rotated to provide the movement in the scanning direction.

3. ☐ Claim numbers \_\_\_\_\_, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING \*

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

## Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.